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Features to Consider When Selecting Displays for Remote Reading

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INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has dramatically increased the use of remote workstations for medical image interpretation. This trend has been discussed nationally on radiology news sites, at meetings, and in medical journals [1-3]. To facilitate this change, the use of nonmedical, commercial off-the-shelf (COTS) displays has become more common. When selecting displays, both technical and practical limitations should be considered. The overarching goal should be to maximize the information presented to the reader in a consistent manner across all devices. Displays that lack adequate technical capabilities or proper calibration can make an image look different than it appears on displays that meet established performance requirements. Additionally, an uncalibrated display may obscure low-contrast features requiring careful and inefficient window width or level adjustment to visualize. Image quality degradation may be difficult for even experienced radiologists to notice. In other words, you cannot always tell what you cannot see. Lastly, display performance often changes over time, meaning that ongoing quality assurance (QA) is needed. Image interpretation is typically performed with displays that meet specific performance requirements and are used in controlled environments with specific lighting conditions, something difficult to achieve with remote workstations using COTS displays. This article provides guidance in terms of display selection, calibration, and QA for the proper use of remote workstations.

DISPLAY SELECTION

All displays have inherent physical properties that affect image appearance. These include (1) luminance (display brightness); (2) response function (the relationship between image pixel values and displayed brightness); (3) uniformity (the variability in luminance across the display); and (4) pixel pitch (how close individual pixels are to each other). Additionally, multiple luminance metrics should be considered, including maximum luminance (L_{max}), minimum luminance, and luminance ratio. The ACR–American Association of Physicists in Medicine (AAPM)–Society for Imaging Informatics in Medicine Technical Standard for Electronic Practice of Medical Imaging [4] and AAPM Report 270 [5] describe these characteristics in depth and recommend performance targets. These are summarized in Table 1.

However, many COTS devices will not meet these requirements. For example, an L_{max} of 350 candela (cd)/m^2 (with a luminance ratio of 350) is recommended, but many COTS devices have an L_{max} between 200 and 300 cd/m^2. In these cases, minimum luminance may be reduced to help maintain the luminance ratio. Unfortunately, this may result in additional challenges in managing the effects of ambient light. Additionally, although medical-grade displays are designed to minimize reflections, COTS displays often have a glossy appearance resulting in increased reflection. This exacerbates the impact of light sources such as lamps and windows, which increases ambient luminance and may reduce image contrast, especially at lower luminances.

CALIBRATION

The luminance response function (LRF) is critical to proper image presentation but can also vary substantially between COTS and medical-grade displays. This section discusses LRF, the importance of properly calibrating the luminance response of displays used for medical interpretation, and how calibration can be performed in a remote setting.

Presentation of medical images requires converting digital image data into a range of luminances. To do this, the image display system assigns a gray level to each pixel. Each gray level corresponds to a different displayed luminance. The relationship between gray level and display luminance is the display's LRF. Proper calibration of the LRF ensures consistent presentation across different displays and adequate contrast across a range of gray levels [5]. The general

Table 1. Recommended performance characteristics for displays used to interpret medical images

Characteristic	Suggested Performance Level for Medical Displays
Ambient illuminance	25-75 lux
Ambient luminance	<0.2 cd/m^2
Minimum luminance	0.8 cd/m^2
Maximum luminance	350 cd/m^2
Luminance ratio	350
Luminance response function	Within 10% of DICOM Grayscale Standard Display Function
Luminance uniformity	LUDM <15%, no clinically significant nonuniformities
Pixel pitch	Approximately 0.200 mm at typical radiology viewing distances

cd = candela; LUDM = luminance uniformity deviation from the median.

recommendation for medical displays is to be calibrated to the DICOM Grayscale Standard Display Function (GSDF). The majority of radiological images are produced with this expectation. However, few COTS displays are calibrated to the GSDF, with most being configured using a standard red green Blue response. Consequently, images may appear too dark in the darkest regions and too bright in the brightest areas when compared with a GSDF-calibrated display. This can substantially and negatively affect the ability to perceive image details in these luminance ranges.

Medical-grade displays are calibrated using built-in photometers or backlight sensors. Proprietary display-vendor software communicates with built-in photometers and adjusts the LRF to provide the desired image appearance. These vendors frequently provide greater bit depth than typical graphics cards, allowing software to fine tune the LRF [6]. Often, the display software is also able to automate calibration and periodic evaluation of conformance.

For most COTS displays, manufacturers do not provide a mechanism to calibrate the LRF. If non-medical-grade displays are used, proper calibration must be achieved through third-party solutions. Much like vendor software, calibrating a display using third-party software requires measuring the palette of possible luminances using an external photometer. The software determines the appropriate calibration for the desired luminance response by loading a modified calibration lookup table to the graphics card, replacing the standard calibration.

As displays age, backlight output degrades, reducing L_{max} and changing the LRF. When the luminance properties of COTS displays change, the lookup table becomes inaccurate, requiring the generation of a new lookup table (ie, recalibration) to maintain image appearance. For medical-grade displays, internal components often automatically adjust the display's luminance to maintain operating levels for extended periods of time without intervention, and automatic consistency checks are

performed to ensure the display continues to operate at the calibrated levels. Almost all COTS displays require periodic manual recalibration to ensure conformance with the DICOM GSDF. Additional qualitative or quantitative QA testing may be necessary to determine when recalibration is needed.

QA

QA testing can be challenging in a remote environment. However, because the clinical task remains the same, these displays should be held to the same standard as those used in a controlled environment. This requires both acceptance and periodic QA testing. Acceptance testing, performed after display selection and calibration, serves two purposes: ensuring that performance is adequate and setting baseline performance metrics with which subsequent routine testing can be compared. It may be easiest to perform acceptance testing immediately following calibration but before the device has been deployed. For testing procedures and performance criteria for medical-grade displays, we refer the reader to AAPM Report 270 [5]. When evaluating commercial displays, some compromise may be necessary. However, displays that substantially underperform (eg, fail to comply with a GSDF LRF or have visibly significant nonuniformities) should not used.

Following deployment, periodic evaluation is necessary to ensure that images continue to be displayed adequately. Performing QA on remote displays is substantially more difficult than QA performed in a central location. Lack of personnel, need for specialized measurement instrumentation, and infection control concerns may make the use of standard QA staff (physicists, engineers, PACS personnel) and methods unfeasible. For example, AAPM Report 270 recommends

quantitative evaluation of luminance response annually for diagnostic review workstation displays [5]. In a remote environment, either the end users need to be trained or equipped to make these measurements or quantitative evaluations may need to be sacrificed. However, there are options to help offset these challenges while maintaining performance. In addition to annual quantitative evaluations, AAPM Report 270 [5] recommends qualitative evaluations of luminance response, ambient luminance, uniformity, and spatial resolution on a quarterly basis. A reasonable approach may involve training radiologists to perform qualitative evaluations. As with other QA programs, the results should be reviewed by a qualified medical physicist.

Remote interpretation of medical images introduces numerous QA challenges. Physicians, physicists, and other personnel must decide how to implement a QA program given their needs and available resources. Regardless, the use of remote workstations, especially those that use COTS displays, makes a well-designed and competently executed QA program especially important.

REGULATION AND ACCREDITATION

Display performance criteria and QA testing requirements vary substantially among accreditation and regulatory bodies [7]. This risks confusion and noncompliance. Although the Joint Commission and the ACR focus most of their requirements on modality displays, local regulatory bodies may have specific requirements for diagnostic displays that differ regionally. As reliance on remote devices increases, users must be aware of performance and QA standards and maintain compliance with accrediting and regulatory bodies.

CONCLUSION

The use of remote workstations for medical image interpretation became more common during the COVID-19 era and continues to expand [1,2]. It is essential that physicians, physicists, PACS personnel, and administrators address the logistical challenges related to remote reading and understand the performance, calibration, and QA requirements necessary to ensure proper image presentation.

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